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# Operating Grain Aeration Systems in the Corn Belt

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In cooperation with Agricultural Experiment Stations
of Indiana and Iowa

## PREFACE

The research on which this report is based is part of a larger project on the aeration of grain in commercial storages. The report discusses methods and procedures for operating aeration systems in the Corn Belt. It supplements the information in Marketing Research Report No. 178, "Aeration of Grain in Commercial Storages," which emphasizes the design, selection of equipment, and installation of grain aeration systems.

Robert W. Thompson, agricultural engineer with the Transportation and Facilities Branch of the Agricultural Marketing Service, and A. C. Lewis, Agricultural Engineering Department, Iowa Agricultural Experiment Station, helped to conduct the research studies. Leo E. Holman, also of the Agricultural Marketing Service, was the supervisory project leader, and helped in preparing this report. Grain storage operators made their facilities available for the tests, and suppliers loaned equipment used in some of the tests.

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# OPERATING GRAIN AERATION SYSTEMS IN THE CORN BELT

By G. H. Foster and B. M. Stahl, agricultural engineers
Transportation and Facilities Branch, Marketing Research Division

## SUMMARY

Aeration is a generally accepted practice for maintaining the condition of stored grain. Properly applied, aeration may be accomplished with upward or downward airflow, with a wide range of airflow rates, and with many different seasonal and daily operating schedules. However, each method of operating aeration systems has some advantages and some limitations which should be recognized.

Various methods of operating aeration systems were observed under test conditions in the Corn Belt. Wheat in deep bins, shelled corn in both deep bins and flat storages, and soybeans in "oil-tank" type of storages were included in the tests. Observations were made of the changes in grain temperatures and moisture, mold development and insect activity, and volume and distribution of air.

The tests show that aeration to prevent moisture migration should be started early and the temperature of the grain kept close to the average temperature of the air during the fall. When the grain cooling is completed before winter, there is little danger of increasing the moisture of the grain near the surface where the air enters. If the grain is aerated during the winter or if it is cooled to below freezing temperatures, slight increases of moisture occur in or near the surface of the grain before the following summer. As the damp grain becomes warmer during the spring and summer, the risk of damage by heating, molds, and insects increases unless grain is aerated further.

The early establishment and continued maintenance of cool grain temperatures by aeration is effective in preventing insect activity, "sick" damage in wheat (a type of storage damage), and increases of mold damage in corn.

In the summer and early fall, aeration fans can be operated day and night, except during rain and fog, in most parts of the Corn Belt. Later in the year when the air temperature is lower and the relative humidity is higher, aeration should be limited to daylight hours on fair days. Manual starting and stopping of aeration fans is acceptable in flat storages aerated at an airflow rate of 1/10 cubic feet of air per minute (c.f.m.) or more if a complete grain temperature change can be made in a week or less. If lower airflow rates are used and if a month or more is required to cool all of the grain in a bin, automatic controls for selecting proper weather conditions for aerating are suggested.

Aeration by upward airflow was satisfactory in all tests in which the cooling was rapid enough to keep the grain temperature within 10° to 15° F. of the average outdoor temperature. Downward airflow is recommended where aeration of warm grain is continued during subfreezing weather.

Airflow rates of 1/50 and 1/100 c.f.m. per bushel were effective in preventing accumulation of surface moisture in corn with 12 percent moisture. In other tests, higher airflow rates were required to cool the grain rapidly enough to prevent insect and mold activity.

The time required to cool a bin of grain by aeration depends on the airflow rate used, as well as other factors such as the methods of operation and the uniformity of air distribution through the grain. Under favorable conditions a complete change in temperature can be made in a bin of grain aerated at 1/10 c.f.m. per bushel by operating the fans about 80 hours in the summer, 120 hours in the fall, and 160 hours in the winter. If the grain is cooled by stages as the temperature of the air falls or if the grain is aerated in the spring and summer, additional fan operation is required.

The cost of operating aeration systems depends largely on the airflow rate used, the depth and kind of grain aerated, and the number of hours fan is operated. Typical operation costs vary from one-twentieth of a cent per bushel for aerating shelled corn in a flat storage to one-fifth of a cent per bushel for aerating wheat in deep bins.

# OPERATING PROBLEMS

Grain aeration systems are being used successfully in all principal grain production areas in the United States, but the methods of operating these systems often vary from one area to the next. This is understandable since aeration systems use natural air, and climatic conditions are not alike in all areas where grain is produced. Further, the purpose of aeration is not always the same from area to area. For example, the prevention of moisture changes during storage is probably the most important use of aeration in northern States where there is wide difference in winter and summer temperatures. This applies particularly to the western part of the Corn Belt where dry weather and low moisture grains are more common than in the eastern part.

In the more humid eastern part of the Corn Belt, the problem of maintaining grain with moistures near the upper limit for safe storage is often of major concern. Here aeration may be used to keep the grain as cool as practical in order to stop molding, heating, and other deterioration processes. This same situation prevails in the southern areas of the United States except that insect control is more of a problem than it is in the northern States. Larger capacity aeration systems are used to speed the cooling during the limited amount of favorable cooling weather in the South.

Summer-harvested grains, particularly wheat and oats, require a somewhat different aeration schedule than corn and other grains harvested in the fall. It is often necessary to remove the harvest heat from wheat and oats quickly to avoid damage from heating and from insects.

Some widely differing procedures for operating aeration systems have been followed in the Corn Belt with satisfactory results. For example, there is still considerable discussion whether the grain should be kept near outdoor temperatures the year around or whether it should be cooled in the fall and winter and kept as cool as possible. In other words, should fall and winter aeration be followed by additional fan operation in the spring and summer? Also, there are proponents of pushing the air up through the grain from the bottom rather than pulling it down from the top and exhausting it at the bottom.

Often there is little basis for a choice of one method of operation over the other, and generally any differences in performance are small. For "problem" grain, such as that with high moisture or damage, the choice of the proper operating procedure becomes more important. Unusual operating circumstances—if aeration is delayed until late winter, for example—must be considered in the choice of alternate methods of operation.

# DESCRIPTION OF TESTS

This report is based on aeration tests conducted in Iowa and in Indiana. Some of these tests were made to obtain information on the proper design of aeration systems in addition to information on operating procedure. The results of the tests are not discussed in detail but are used as examples to illustrate specific points on operating aeration systems. Some comparative data on temperatures and moistures of grain are included in the Appendix.

The tests were made in deep bins of various heights and diameters, in flat storages of different sizes, and in "oil-tank" storages. Various sizes of aeration systems were studied as well as a number of different methods and schedules of operation. Grain temperatures were measured by thermocouples in all deep bins, and by either thermocouples or probe thermometers in all flat storages. The grain was sampled by conventional grain probes while in the bin storage and by "cutting" the stream of grain while emptying the bin. Standard instruments and gages were used to determine the airflow and the pressure required to force the air through the grain. Recording instruments provided continuous records of outdoor temperature and relative humidity.

## AERATION TESTS IN IOWA

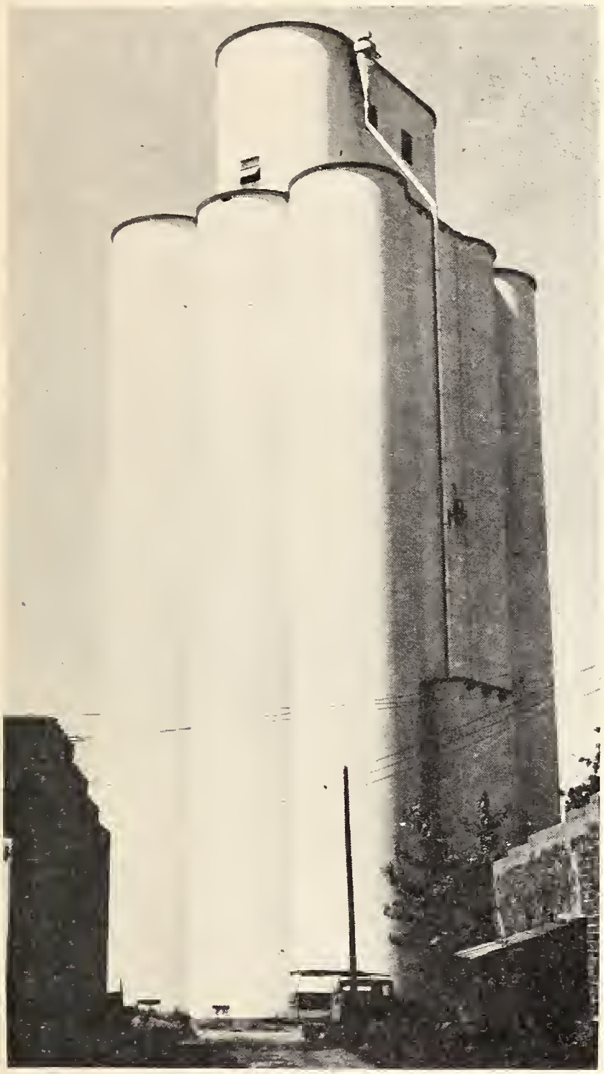
A series of aeration tests was conducted in nine deep bins (upright storages) at Boxholm, Iowa (fig. 1). These tests were made to study and demonstrate the effectiveness of fall and winter aeration versus fall, winter, and spring aeration; downward versus upward movement of air through the stored grain; and various airflow rates for preventing moisture accumulation in the top layers and also in the subsurface layers to a depth of 15 feet.

Seven of the 9 bins were 15½ feet in diameter and 108 feet deep with a capacity of 16,880 bushels per bin; each was equipped with a semicircular, perforated floor duct. The other two bins were over the elevator driveway; they

were about 90 feet deep and had a capacity of 6,600 bushels per bin.

Approximately 130,000 bushels of shelled corn were placed in these 9 bins during the period of July through September 1955. The unofficial grade determination made when the corn was received showed an average of 12.2 percent moisture and 5.0 percent damage. However, about 18 percent of the corn had a moisture content below 12 percent; about 50 percent, a moisture content between 12.0 and 12.5 percent; about 30 percent, a moisture content between 12.6 and 12.9 percent; and about 2 percent, a moisture content between 13.0 and 13.6 percent.

The tests were started in October 1955 and were continued until July 1958 when the bins were emptied and final samples obtained.



NEG. BN-8400-X

FIGURE 1.—Elevator in which the Iowa tests were conducted.

None of the corn was turned or fumigated during the tests. The temperature of the corn when initially stored ranged from 70° to 85° F.

The various tests are described below:

**1 Bin.**—Air moved downward through the corn in the fall and winter and again in the spring at a rate of 1/10 c.f.m. per bushel. A 5-horsepower electric motor was used to run the fan. A humidistat and a thermostat were used to control the fan operation.

**2 Bins.**—Air moved upward through the corn during the fall and winter only at a rate of 1/10 c.f.m. per bushel. A portable fan and 5-hp. motor were used to aerate the corn in the two test bins and one additional bin not included in the tests. Fan operation was controlled manually.

**2 Bins.**—Air moved downward through the corn in the fall and winter and again in the spring at a rate of 1/30 c.f.m. per bushel. A 1-hp. motor and fan were used on each of the two bins. A humidistat and thermostat were used to control the fan operation.

**1 Bin.**—Air moved downward through the corn during the fall and winter and upward during the spring at a rate of 1/50 c.f.m. per bushel. A ½-hp. motor and fan controlled by a time clock was operated daily from 10 a.m. to 6 p.m. in the fall and winter, and daily from 10 p.m. to 6 a.m. in the spring.

**1 Bin.**—Air moved downward through the corn in the fall and winter and again during the spring at a rate of 1/100 c.f.m. per bushel. A ⅙-hp. motor and fan were controlled manually.

**1 Bin (overhead).**—The grain in the upper part of the bin was aerated with a 1/20-hp. motor and fan attached to a vertical 6-inch-diameter aeration duct inserted in the top 12 feet of grain. The bottom 9 feet of this duct was perforated. The fan was controlled manually in the fall and winter and again in the spring.

**1 Bin (overhead).**—Same type of bin as previous one, but the corn in this bin was not aerated.

## AERATION TESTS IN INDIANA

Factors influencing the operation of aeration systems were studied in Indiana tests conducted from 1955 to 1958. A total of 16 commercial storages of grain were observed under test conditions for one or more years. Included were seven corn storages, seven wheat storages, and two soybean storages. These tests are described below:

Comparisons were made between upward and downward airflow in two similar flat storages 40 feet wide and 120 feet long, each filled with about 60,000 bushels of

shelled corn (fig. 2). A single center aeration duct was used. The storages were served with identical fans, each driven with a 3-hp. motor. The airflow rate was estimated at 1/10 c.f.m. per bushel. Both fans were automatically started and stopped from a single control point. The controls used were a high-limit thermostat, a low-limit thermostat, and a humidistat, all connected in series.

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FIGURE 2.—One of the two flat storages in which comparisons were made between aerating with upward and with downward airflow.

Year-round aeration versus aeration in the fall and winter only was observed and compared in three flat storages of shelled corn varying in capacity from 27,000 to 48,000 bushels. Each storage had a single center aeration duct. The three storages were aerated with one 3-hp. portable fan. The airflow rate varied from 1/5 to 1/7 c.f.m. per bushel. The fan was controlled automatically by a high-limit thermostat and a humidistat connected in series.

Shelled corn stored in two tank-type storages 45 feet in diameter and 70 feet high was cooled by aeration with a combination of upward and downward airflow. A duct system composed of a center duct with three smaller lateral ducts on each side was constructed of concrete blocks, wood planks, and wire screen. The airflow rate of slightly less than 1/10 c.f.m. per bushel was supplied by 20-inch propeller fans each driven by a 7½-hp. motor. The fans were started and stopped manually.

Two upright storages of wheat, each 22 feet in diameter and 120 feet deep with a capacity of 35,000 bushels, were used in a study of minimum airflow rates for aeration. A 3-hp. fan was used on one bin and provided downward airflow at a rate of about 1/60 c.f.m. per bushel. A single V-shaped perforated metal duct 16 feet long was located on the floor at the bin center. The other bin was used as a check. The fan was controlled automatically by a high-limit thermostat, a low-limit thermostat, and a humidistat, all connected in series.

Two 60,000-bushel storages of wheat 150 feet deep and 25 feet in diameter were used in a study of the effectiveness of aeration in preventing deterioration of wheat which is near the upper limit of moisture recommended for longtime storage. An extensive duct system consisting of a main center duct and 10 smaller laterals was cast in the concrete bin bottom. Air was moved downward through the wheat at a rate of 1/40 c.f.m. per bushel. On each bin a fan driven by a 7½-hp. motor was controlled automatically by a high-limit thermostat, a low-limit thermostat, and a humidistat, all connected in series. Wheat in the other bin was not aerated.

Three bins of wheat were used in a test of upward airflow in deep bins. Each bin was 30 feet in diameter and 110 feet deep, and held 60,000 bushels. The duct system was attached to the bottom of the hopper bin and positioned radially around a center drawoff. A positive discharge rotary blower driven by a 30-hp. motor was permanently connected to the three bins through a manifold duct system. The airflow rate used ranged from 1/20 to 1/40 c.f.m. per bushel. The blower was started and stopped manually.

Two large oil-tank storages were used in aeration tests with soybeans. One was 82 feet in diameter, the other 120 feet in diameter, and each about 75 feet deep at the peak of the roof. The aeration ducts were half-round perforated metal with an 18-inch radius. Two lengths of duct were positioned on either side of the center in the smaller bin, and three lengths were used in the larger bin. The smaller bin was aerated with two fans driven by 5-hp. motors, and the two fans on the larger bin were driven by 15-hp. motors. The airflow rate provided for each storage averaged approximately 1/20 c.f.m. per bushel. The fans were controlled automatically with a high-limit thermostat, a low-limit thermostat, and a humidistat, all connected in series.

## MINIMIZES MOISTURE MIGRATION AND ACCUMULATION

In the Corn Belt, aeration is particularly useful for equalizing grain temperatures to prevent, or at least to minimize, moisture migration in stored grain. Variations in grain temperatures cause moisture changes in localized areas of the grain bulk during the fall and again during the spring months. Resulting moisture accumulations may become so great that considerable grain deterioration may take place during warm weather from increased mold and insect activity.

Aeration to equalize stored grain temperatures may be started whenever the average daily air temperature is 10° to 15° below that of the warmest part of the stored grain. If aeration is delayed so that the temperature of the subsurface grain is 70° F. or higher when freezing air temperatures become common (mid-November), moist air rising from the warm grain will condense on the cold surface layers. As a result, spoilage and crusting in the surface grain and condensation on the cold roof and upper wall surfaces can occur before aeration is started.

The hazard of delaying aeration was demonstrated in two of the Iowa tests. During the second storage season, aeration was delayed until December in two of the deep bins. As a result of this delay, the moisture content of the top 6 inches of corn increased to 29 percent in one bin and to 22 percent in the other before aeration was started. Also, in both bins the moisture content increased to about 16½ percent in the second 6 inches of corn (bins 5 and 6, table 1, Appendix).

In both Indiana and Iowa tests moisture content increased in the layers of grain 1 to 5 feet below the surface during the spring months following fall and winter aeration (fig. 3 and table 1, Appendix). This moisture buildup apparently was caused by warm, outside air moving downward into the subsurface grain layers where some moisture was transferred to the cooler grain. The increase in moisture appears to be associated with the difference between the air and grain temperatures. Where the grain was cooled to below freezing temperatures, serious problems with subsurface moisture accumulations have been observed. For this reason many operators in the Corn Belt area do not cool the grain to below freezing temperatures unless it is planned to warm the grain by additional aeration in the spring.

Grain with moisture contents as high as 14 to 15 percent will not deteriorate rapidly if grain temperatures remain below 50° F. However, as the grain becomes warmer during the spring season, the risk of damage by molds and insects increases. This is discussed further under the heading of Spring and Summer Aeration.

## DETERS MOLD GROWTH AND INSECT ACTIVITY

Mold growth and insect activity are two important causes of grain deterioration in storage. Both are favored by excess moisture and warm temperatures. Molds and insects are involved in the damage caused by moisture migration and accumulation. Perhaps of equal importance is the slower and less noticeable deterioration that takes place in the mass of grain not affected by moisture migration. Certain of the molds, such as those associated with sick wheat and blue-eye mold in corn, have been reported in grain considered safe for storage.[1] This problem is more prevalent in the eastern part of the Corn Belt where it is common to store grain near the upper limit of moisture for safe storage. Under these conditions, aeration is used to establish and maintain a low grain temperature to deter mold growth and insect activity, as well as to prevent localized moisture accumulation. In storable grain, most molds grow slowly below 70° F., and insect reproduction is retarded at temperatures below 60° F.

A test completed in 1958 on aerating wheat in the eastern part of the Corn Belt illustrates the part aeration may play in reducing sick damage in wheat. Two 60,000-bushel concrete storages were filled with soft red winter wheat on August 6 and 7, 1957. The filling stream was split, with half going into an aerated bin and half into a check bin without aeration. The initial moisture content of the wheat was 13.8 percent and the initial temperature 84° F.

The wheat temperature in the aerated bin was gradually reduced to 50° over a 20-week period and the wheat remained in storage a total of 39 weeks (fig. 4). After 14 weeks, wheat in the unaerated check bin showed some temperature increase in one area and was turned and stored in another bin for an additional 7 weeks. This wheat was then turned into an aerated bin and quickly cooled to near freezing temperatures.

Both bins were emptied about the same time and the wheat sampled for grade determination

[1] "Sick wheat" is a term applied to a type of storage damage usually associated with brown discolored germs, evidence of dead deteriorated germs, and of other damage to the kernel.

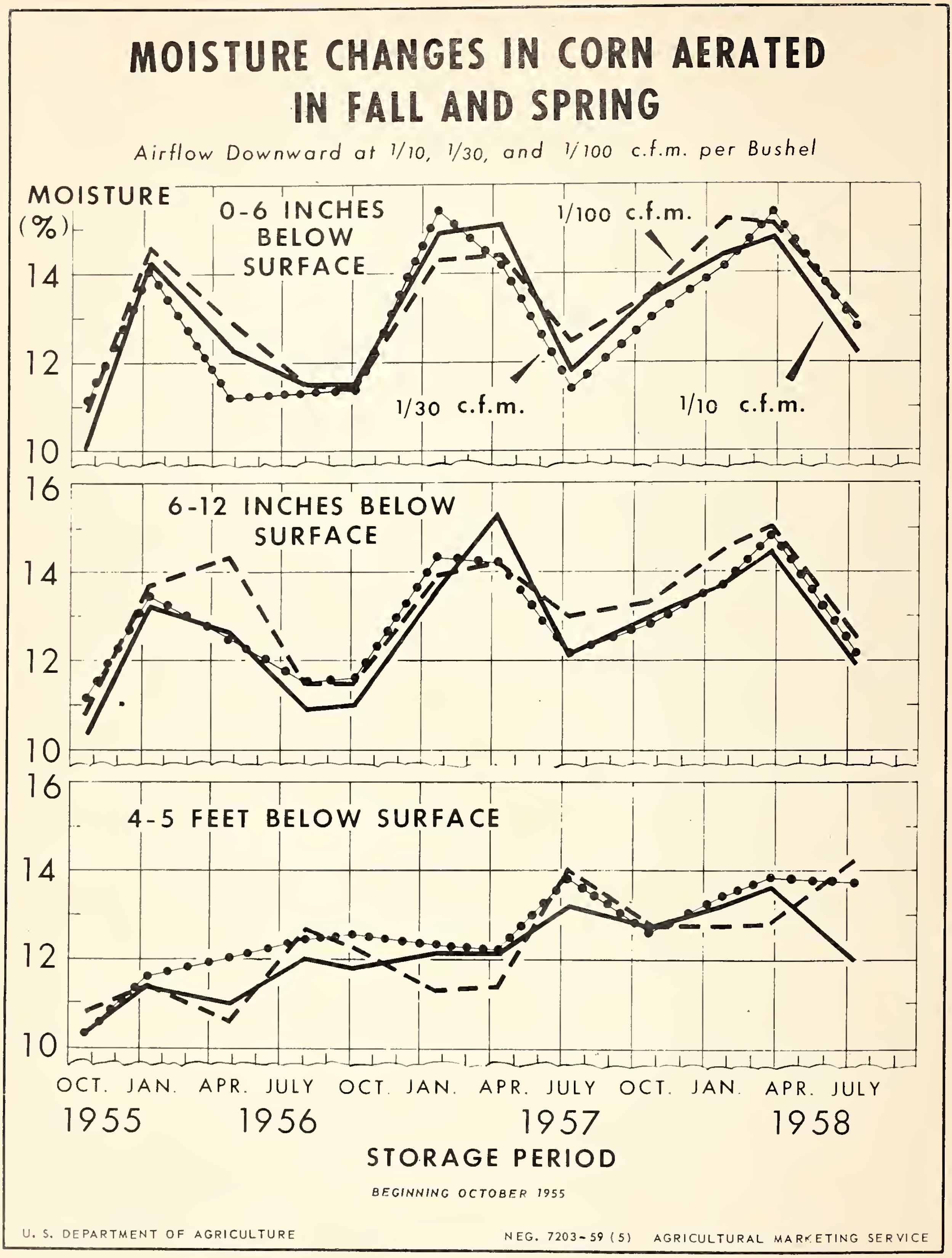
MOISTURE CHANGES IN CORN AERATED
IN FALL AND SPRING
Airflow Downward at 1/10, 1/30, and 1/100 c.f.m. per Bushel
MOISTURE
(%)
0-6 INCHES
BELOW
SURFACE
1/100 c.f.m.
1/30 c.f.m.
1/10 c.f.m.
6-12 INCHES BELOW
SURFACE
4-5 FEET BELOW SURFACE
10
12
14
16
OCT. JAN. APR. JULY OCT. JAN. APR. JULY OCT. JAN. APR. JULY
1955 1956 1957 1958
STORAGE PERIOD
BEGINNING OCTOBER 1955
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Figure 3

and mold damage. Wheat in the aerated bin had 2.1 percent sick damage while that in the check bin had 3.6 percent sick damage. Slight germ discoloration was reported in an additional 2.5 percent of the sample from the aerated bin, and 10.2 percent of the germs were discolored in the sample from the check bin. These differences would likely have been greater had the check bin received no aeration before the end of the test period. In this test, holding the wheat at the lower temperature appeared to be a deterrent to sick damage.

The importance of cool grain temperatures in the control of insects was demonstrated in one aeration test with wheat in Indiana. An upright storage was filled in July with 34,000 bushels of No. 1 red winter wheat as received from country shipping points. The average temperature of the wheat when placed in the bin was 87° F. Intermittent aeration was started immediately, when the outdoor temperature was below 75° and the relative humidity below 80 percent. A total of only 500 c.f.m., about 1/60 c.f.m. per bushel, was used. The air was pulled from the top down and exhausted by the fan.

The fan operated about 220 hours during the first 6 weeks without lowering the grain temperature appreciably. The warm weather between periods of fan operation warmed the top layers of grain about as much as they were cooled during fan operation. During the next 5 weeks the average grain temperature was reduced about 10° F. with some 170 hours of operation. However, all the temperature reduction was in the top quarter of the bin and the grain temperatures in the bottom remained above 80° F. At this time, about October 1, the temperature of the wheat in the bottom of the bin started to increase and some bran bugs were blown out through the fan. Further operation of the fan failed to control the insect activity and the grain was turned and fumigated. In other tests in which the temperatures of the grain were lowered to 70° or below by October, no serious insect problem was encountered.

The relation between grain temperature and insect activity was again demonstrated in aeration tests with soybeans. The beans were stored in a 250,000-bushel oil-tank storage 82 feet in diameter. The beans were about 55 feet deep at the sidewall and about 75 feet deep in the center. The storage was filled through a center hatch, and consequently most of the

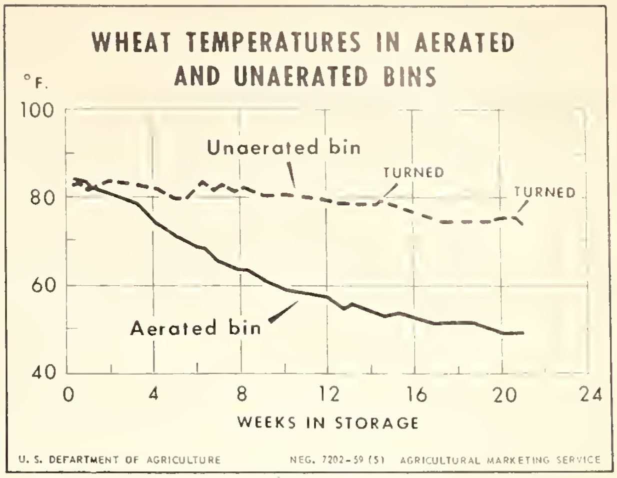


Figure 4

foreign material accumulated in the center where the beans were deepest. The aeration fans were installed nearly 2 months after the storage was filled. The fans operated only 10 hours before December 1. By that time the temperature of the beans in the center of the bin had increased to 96° F. from an initial temperature of 84°.

During the next 8 weeks all the beans in the storage except those within about 15 feet of the center were cooled to 40° F. The fan had operated 283 hours and the airflow had averaged 1/20 c.f.m. per bushel. The temperature of the beans in the center directly under the hatch continued to increase slightly during this period. It was necessary to reduce the depth of beans in the bin in order to increase the airflow sufficiently to arrest the heating. When the beans were unloaded, considerable insect activity was evident in the area where heating occurred, but none in the other parts of the storage.

The test was repeated the following year under similar conditions, except that aeration was started in October as soon as the beans were put in storage. All the beans except those in the center of the bin were cooled to below 50° F. by mid-November. By continuing aeration until January 1, the temperature of the beans in the center was also lowered to 50°. There was no evidence of insect activity anywhere in the beans when they were removed from the bin late the following summer.

## SATISFACTORY GRAIN TEMPERATURES

The temperature at which grain should be held in storage is mentioned in discussions of other subjects in this report. However, the importance of temperatures in maintaining grain in good condition warrants further emphasis.

The length of time the grain will be in storage, the possibility of moving the grain in warm weather, and the need for fumigation should be considered when determining how much to cool the grain. There are certain hazards when grain is overcooled.

Generally, the temperature of the grain should be kept above the freezing point. If the grain is to be held through a full season or longer, the grain can be cooled to near 32° F. in the fall and winter and then kept as cold as possible through the warm months. If the grain is stored through the winter months only and is to be moved during warm weather, a minimum grain temperature of 50° is recommended. At this temperature there is little danger of water condensing on the cooled grain if it is moved out of storage during warm, humid weather.

Grain temperatures above 60° F. are required for effective use of certain fumigants. Aeration systems can be used in the spring or summer to warm the grain before fumigation.

## SPRING AND SUMMER AERATION

During fall and winter aeration, moisture may increase in the top layers of grain if the aeration fan is operated when the weather is too cold or damp. This increase in moisture may also result from overcooling the corn during the winter. As the damp grain in the surface layers warms up in the spring, it may be damaged by molds and insects. Additional aeration during the spring when the air becomes warm and dry may be desirable to dry this damp grain to prevent excessive damage. Of course, the grain will be warmed by spring aeration and the operator must decide whether localized damage will be severe enough to warrant warming the entire lot of grain. The loss in market value from a slight increase in damage to the entire lot may be greater than the loss from serious localized damage in the small areas.

Many operators wait until heating actually develops in localized areas of high-moisture grain before starting to aerate in the spring or summer. Slight increases in grain moisture near the surface may not cause heating until late in the summer, if at all. The grain should be inspected and sampled regularly to spot any high-moisture areas that show signs of causing trouble.

In the Iowa tests spring aeration was effective in reducing subsurface moisture accumulations. In the tests with spring aeration the moisture content had increased 1 to 3 percent in the surface layers of corn by late winter or early spring (fig. 3). In each test, spring aeration reduced these moisture accumulations. The two tests with fall and winter aeration only were both with upward airflow at 1/10 c.f.m. per bushel. They showed no increase in surface or subsurface moisture in the spring.

In one Indiana test, shelled corn was held in two flat storages through the summer without aeration, while corn in a third was aerated intermittently. In the summer-aerated bin the moisture content in the top 5 feet of grain was gradually reduced from a high of 14.2 percent, observed on the first sampling, June 23. In one of the bins without summer aeration, moistures at one point in the top 5 feet of grain increased slightly during the summer, reaching a high of 14.6 percent by August 20. In the other bin, moistures in the top 5 feet were generally between 14 and 15 percent on June 23 and remained in this range until August. At that time heating started and the temperature of the grain at some points rose to 110° F. Then the fan was operated with upward airflow between 1 and 2 days on each bin. This reduced the temperatures to near outdoor temperatures and lowered the moisture of the grain in the affected area by about 1 percent. No further treatment was required until the regular aeration schedule was resumed in the fall.

Some precautions should be observed when stored grain is aerated in the spring and summer. It is safer to start warming the grain in April or early May, before hot weather arrives. If the grain is warmed later in the summer, aeration should be continued until all the grain in the bin is near air temperature, as explained below.

When warm air is passed through colder grain, some moisture is transferred from the air to the grain, and if the grain is cold enough,

water may condense on it. This condensation usually occurs where the warm air first strikes the cold grain. As aeration continues, the zone between the warm and cold grain moves in the direction of the airflow. Any moisture transferred to the cold grain dries out again after the grain is warmed.

It is important to keep the warming zone moving until all the grain is raised to the temperature of the air, particularly in deep bins. This was illustrated in one Indiana test where shelled corn that had been cooled to about 50° F. during the previous winter was aerated for a few hours each week during the summer. Upward airflow was used to push cooler air from the lower parts of the bin through the top surface where the temperatures of the corn were increasing and some insect activity was starting. This top layer was cooled quickly, but the corn in the bottom of the bin was raised to near summertime temperatures. After about 5 weeks, corn in the bottom third of the bin was warmed to 80° and the top two-thirds remained around 55°. At that time the zone between the warm and cold corn began to heat rapidly and reached temperatures of over 100°. It was necessary to empty the bin to stop the heating. If the high-moisture zone had been kept moving at a faster rate by more continuous aeration the entire bin of corn undoubtedly would have been warmed without difficulty.

Loss of weight through drying of the grain may be another important consideration in summertime aeration. Air at 80° F. will hold nearly four times as much moisture per cubic foot as air at 40°. Thus, moisture changes in grain will occur about four times faster in the summer than in the winter at the same relative humidity and airflow rate. Since the relative humidity of the air in the summer averages lower than in the winter, some weight loss through drying can be expected with extended summer aeration.

## OPERATING PROCEDURES

### OPERATING SCHEDULES AND CONTROL METHODS FOR AERATION FANS

Aeration fans are operated with a variety of daily schedules, ranging from automatically controlled intermittent operation to continuous operation. Operation at preselected times each day with the fan automatically started and stopped by a time switch is also practiced. Various schedules are followed by operators who control their fans manually.

Both the manual control and automatic control methods employed in the Iowa and Indiana tests appeared to perform satisfactorily. Observations on the various methods of controlling aeration fans are summarized in the following discussion.

Good operating weather is often missed when fans are started and stopped manually. Too often operating periods are selected for the convenience of the operator rather than to take advantage of the most favorable weather for aerating. This becomes serious in systems where low airflow rates are used. In upright storages filled with small grain, airflow rates of 1/20 c.f.m. per bushel, and lower, are common. With low airflow rates, it is important to use all the favorable aerating weather available, as a period of a month or longer is often required to reduce the temperature of the grain to the temperature of the air. Thus manual control is not well adapted to the aeration of upright storages. From late summer to about Thanksgiving, aeration fans in many parts of the Corn Belt can be operated day and night, except during rain and fog. In the winter it is usually necessary to limit operation to daytime hours to prevent adding moisture to grain.

When aeration systems are controlled by time clocks, the operating periods are based on average weather conditions. For example, operation may be limited to between 6 a.m. and 12 noon, which usually is the coolest part of the day with relative humidities satisfactory for aeration. Many prefer this method of starting and stopping aeration fans since it does not require calibration of thermostats and humidistats. On the other hand, it does not prevent operation of fans when unfavorable weather occurs.

The control settings cannot be too restrictive or there will be little fan operation. Temperature controls should allow operation over a range of air temperatures of at least 10° to 20° F., and this range should include the average temperature for the time of the year. Humidistats are normally set so the average relative humidity of the circulating air will be such that it will neither wet nor dry the grain. Since there is normally a daily cycle of relative humidity running from high to low to high again, the fan can be turned on when the relative humidity is somewhat above the average desired. Fan operation during the low part of the cycle will balance the operation when the humidity is higher than the average. For the Corn Belt, humidistat settings to stop aeration when the relative humidity is above 80 percent

is satisfactory in the fall. If aeration is continued through the winter, it is better to limit fan operation to periods when the humidity is 70 percent or below.

Automatic controls must be kept in good working order and set properly or their effectiveness in selecting proper weather for aeration is lost. In both the Iowa and the Indiana tests, the control systems required frequent inspection and servicing. Time clocks must be reset each time electrical service to the control is interrupted. Because humidistats are particularly sensitive to dust, the moisture sensing elements must be kept clean. Sensing elements made of hair should probably be replaced every 2 years.

A control system employing a high-limit thermostat, a low-limit thermostat, and a humidistat, all connected in series, is used widely in the Corn Belt area. The high-limit thermostat prevents fan operation when the temperature exceeds the set point, and the low-limit thermostat prevents operation when the temperature is below its set point. The humidistat prevents operation when the relative humidity is above its setting. A typical control circuit employing the above components and including an operation recorder to show when the fan runs is shown in figure 5.

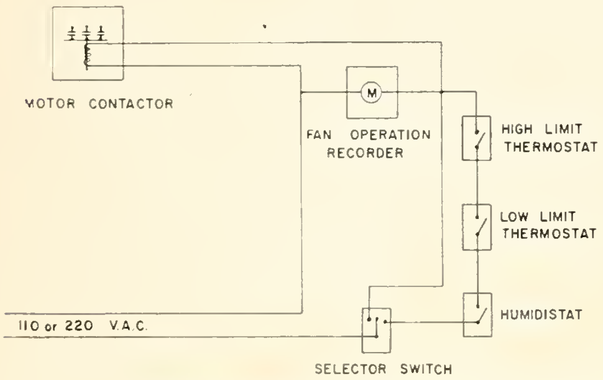


FIGURE 5.—Typical control circuit for aeration fans.

Construction of the control housing and location of the control center are important (fig. 6). The control elements should be surrounded by air in the same condition as that being moved through the grain. The controls should not be located in excessively dusty or windy locations. A well-ventilated enclosure in a shady location is recommended.

## DIRECTION OF AIRFLOW

The fan and duct system are usually installed at floor level. Downward air movement requires suction operation of the fan, while pres-

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FIGURE 6.—The fan control and instrument shelter at the left is located on the shady side and 6 feet away from the storage.

sure is used to force the air upward. Systems in which the fans are located at the top of the bin or those in which air movement is horizontal appear satisfactory but are not included in this discussion.

Air movement downward through the grain has been generally recommended for aeration. With air moving downward the comparatively warm, moist air is exhausted through the warm grain around the aeration duct and not through the cooler surface grain where some condensation might occur. Also, the natural tendency for air to move upward from the warm grain through the cool upper surface is offset by moving the air downward during aeration. With this method the upper layers of grain are cooled first, and thus the danger of moisture rising from the subsurface grain and condensing on the surface grain is reduced. This is an important consideration if a portable fan is used to aerate several bins on a rotation basis. The upper layers of grain in each bin serviced by a portable fan can be cooled within a relatively short time. In contrast, with air moving upward the top layers of grain will be the last to cool.

When airflow is upward, aeration should be scheduled so that the difference between the temperatures of grain and air is held to a minimum. In two Indiana wheat tests with upward airflow, aeration was not completed by December 1, when a period of cold weather arrived with nightly minimums of around 15° F. At that time the average grain temperature had been reduced from the high eighties to the sixties, but some grain near the top still had temperatures ranging up to 85°. Moisture condensed on the underside of the bin roof and accumulated in the surface layers causing some heating and sprouting. By December 15, the

temperature of the wheat in the top of one of the bins was reduced to below 60° and the wheat began to dry. When later inspected and sampled there was a crust 1 to 2 inches deep at the highest point of the grain surface and also under the metal ventilator and hatch covers where moisture had condensed and dripped back on the wheat. Wheat in the other bin had cooled slower, and some of the surface grain continued to heat through December. It was necessary to break up the surface crust twice before the cooling zone reached the top surface and the moist wheat began to dry.

Wheat aeration tests conducted in Indiana in 1955 and 1956 showed one advantage of upward airflow. Some 60,000 bushels of wheat in an upright storage were cooled to between 40° and 50° F. in the winter of 1955 (fig. 7). During storage through the following summer without aeration the temperatures in the lower two-thirds of the 110-foot depth of wheat increased only to between 50° and 60°. The wheat in the upper part of the bin increased to 90°. In the second year, the high wheat temperatures near the top were pushed out with only 175 hours of aeration with upward airflow. Thus a satisfactory grain temperature was reestablished with less than one-half of the 375 hours of aeration required to originally cool the grain.

Similar results were observed in a shelled corn storage 45 feet in diameter and 70 feet high. The fan was operated on suction the first year, but was turned around and operated on pressure the second year. Uniformly cool temperatures were established during the second season with only about one-third as much operation as was required the first year. By not pulling the heat from the warm corn near the top down through the cooler corn below, the saving in operating time was substantial. This saving may not be as great in bins of smaller diameter where the grain warms up more rapidly during the summer.

More recent tests compared upward and downward airflow in two identical flat storages of shelled corn but provided no conclusive advantages for either method of operation. The shelled corn was cooled by stages starting in late August or early September. Temperatures of the corn were kept within 10° to 15° F. of the average outdoor temperature as the weather cooled off in the fall. This procedure may prove essential to the successful use of upward airflow. However, if aeration is delayed until cold weather arrives, moving the air downward through the grain and exhausting it through the grain around the aeration duct—not through the cold grain near the top surface—appears to be the safest procedure.

These tests in flat storages also showed that there is a tendency for moisture to increase where the air first enters the grain. This apparently occurs when the relative humidity of the circulating air is too high or where grain in the surface layers becomes moist between periods of aeration. As an illustration of this, the following moisture data were taken in April following fall and winter aeration of the corn in the two flat storages:

| Sampling location | Moisture content of grain | | | |
|---|---|---|---|---|
| | Downward airflow | | Upward airflow | |
| | Average | Range | Average | Range |
| | *Percent* | *Percent* | *Percent* | *Percent* |
| 0 to 2 feet below surface........ | 13.5 | 12.3–14.3 | 13.3 | 12.9–13.6 |
| 0 to 2 feet from floor duct..... | 12.7 | 12.4–12.9 | 13.6 | 13.3–14.1 |

With the downward airflow the moisture in the grain in the upper surface layers, where the air entered the grain, was higher than that near the duct. This relation was reversed with the upward air movement although the difference was not as great.

A moisture increase in the grain near the duct was also evident in one Iowa test in which upward airflow was used in the spring. When the bin was emptied, caked grain around the duct indicated this grain had been wet at one time. The spring aeration was limited to night operation, when the relative humidity of the air was higher than in the daytime in order to offset any weight loss incident to the aeration process. This probably is the reason why this bin showed evidence of a moisture increase near the duct while the two bins with upward airflow in the fall did not.

The design of the duct systems used in flat storages is important in determining whether airflow should be upward or downward. If the ducts are too long or if they are too small in cross-section, or both, there is uneven airflow and uneven cooling of the grain. This situation is much more pronounced if the air is pulled downward through the grain than if the air is pushed upward. In suction systems the airflow through the grain nearest the fan end of the duct is higher than that at the end farthest from the fan (fig. 8). The grain farthest from the fan cools slower than that nearer the fan. This unevenness of airflow can be overcome by increasing the size of the duct, by reducing its length, or by changing from downward to upward air movement through the grain.

Some information on the influence of size and length of aeration ducts on uniformity of air-

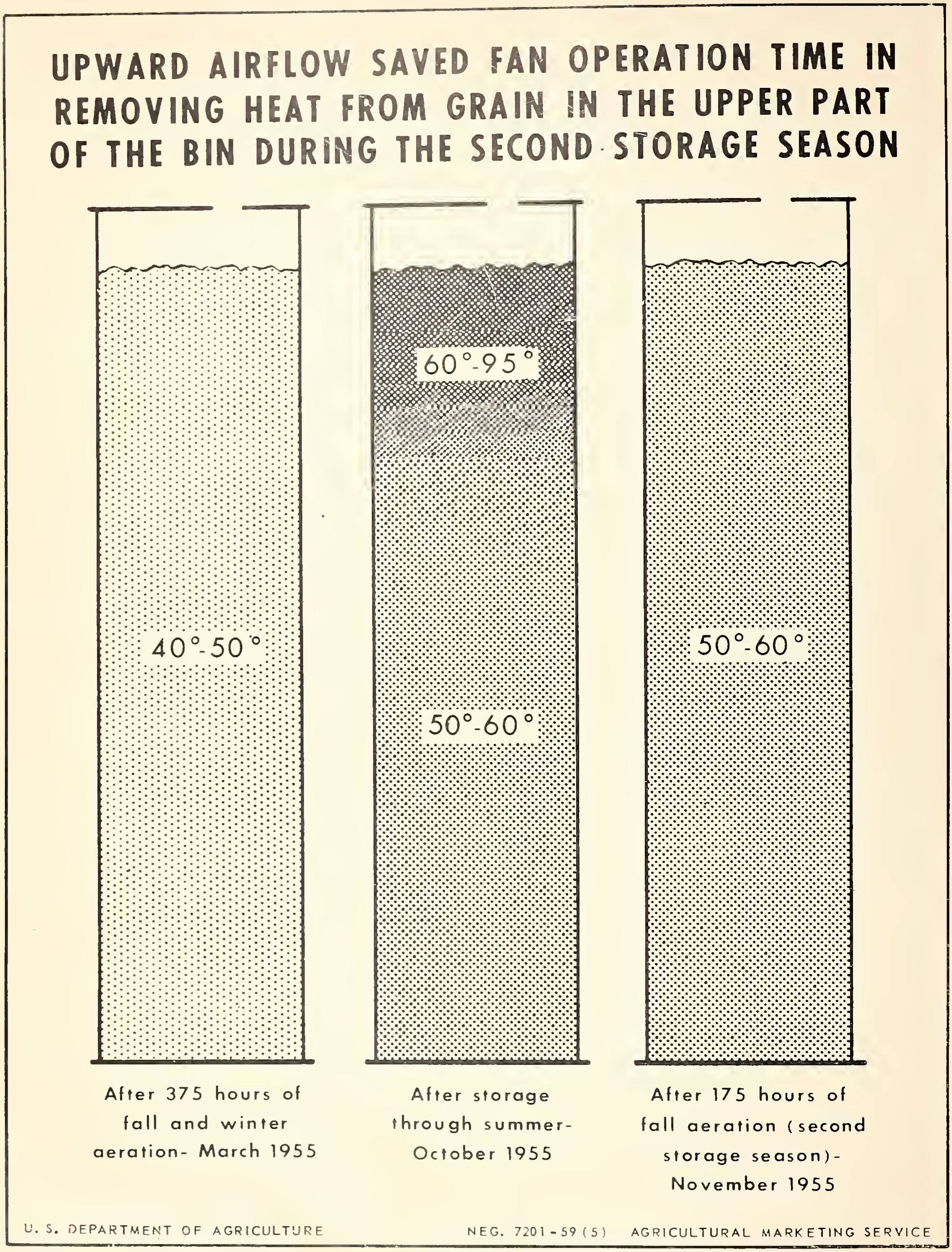
UPWARD AIRFLOW SAVED FAN OPERATION TIME IN REMOVING HEAT FROM GRAIN IN THE UPPER PART OF THE BIN DURING THE SECOND STORAGE SEASON
40°-50°
60°-95°
50°-60°
50°-60°
After 375 hours of fall and winter aeration- March 1955
After storage through summer- October 1955
After 175 hours of fall aeration (second storage season)- November 1955
U. S. DEPARTMENT OF AGRICULTURE
NEG. 7201-59 (5)
AGRICULTURAL MARKETING SERVICE

FIGURE 7

COMPARISON OF UPWARD AND DOWNWARD AIRFLOW IN LONG AERATION DUCTS

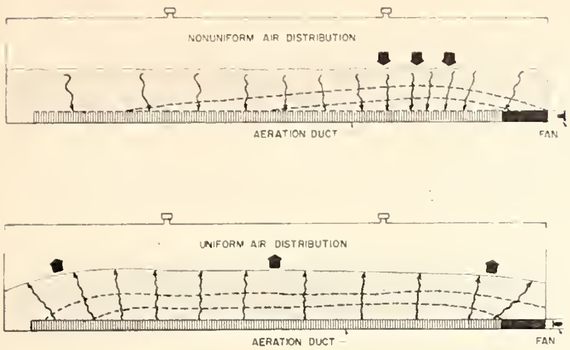


FIGURE 8

flow through grain was obtained during a study of this problem in 1957. The studies were made in flat storages equipped with floor ducts along the length of the building. The uniformity of airflow was estimated from measurements taken of the static pressure developed in moving air through the grain. If the maximum air velocity exceeded 2,000 feet per minute in ducts 50 feet to 130 feet long, the static pressure at the fan end of the suction systems was 3 to 5 times greater than at the other end of the duct. When the fan was changed to force air into the duct and upward through the grain, the static pressure was about the same at both ends of the duct. If the ducts were large enough, and the maximum air velocities in the duct were only 600 to 800 feet per minute, the indicated uniformity of airflow through the corn was satisfactory for either downward or upward air movement.

## AIRFLOW RATES

If one or more fixed fans serve a single storage, the airflow rate is established. In systems in which one fan serves several bins, airflow rates can be changed by aerating a greater or smaller number of bins at one time. This applies to multiple bin systems with fixed fans and to a lesser extent to multiple bin systems using portable fans. To this extent, airflow rate is pertinent to this discussion on operating aeration systems.

Airflow rates of 1/10, 1/30, 1/50, and 1/100 c.f.m. per bushel were used in the aeration tests in Iowa. With these airflow rates and under the conditions of these tests, the shelled corn remained in storage without being turned for three storage seasons (October 1955 to July 1958) with little or no deterioration in market value. It should be emphasized that the moisture content of this corn when stored averaged only 12.2 percent. The tests provided no assurance that all of the airflow rates used would be satisfactory for grain with higher moisture content and under different operating conditions.

The examples from the Indiana tests cited under Mold Growth and Insect Activity also apply to this section. The insect activity reported can be attributed to inadequate airflow rates and the resultant slow cooling. In the wheat tests it was the total amount of airflow that was inadequate, while in the soybean tests it was the uneven distribution of airflow that caused trouble.

The airflow rate used must be adequate to cool all the grain served by the system before undesirable changes take place. If one fan is used to aerate two or more bins in succession the airflow rate must be adequate to cool all the grain in all the bins before moisture migration or other damaging changes occur. Aerating two bins, one at a time, with 1/10 c.f.m. per bushel will not complete the cooling of all the grain any faster than supplying 1/20 c.f.m. per bushel to both bins at once.

## TIME REQUIRED FOR COOLING GRAIN

The time required for cooling a bin of grain to near the temperature of the outside air depends largely on the airflow rate used. Other contributing factors are the amount of drying that accompanies the cooling and the uniformity of airflow through the grain. The aeration time required is essentially the same when the grain is being warmed as it is when the grain is being cooled.

As a general guide, the following are typical of the number of hours fan must be operated to cool grain to near existing air temperatures with an airflow rate of 1/10 c.f.m. per 60-pound bushel:[2]

| | |
|---|---|
| Summer aeration | 80 hours |
| Fall aeration | 120 hours |
| Winter aeration | 160 hours |

The time required for cooling with airflow rates other than 1/10 c.f.m. per bushel is inversely proportional to the airflow rate used. That is, if the airflow rate is reduced to 1/20 c.f.m. per bushel, the estimated hours of fan operation are double those given above.

The number of days required to cool a bin of grain will depend on the percentage of each day that is suitable for aeration. With an average of only 10 hours per day with weather suitable for aeration, the 120 hours of fan op-

[2]For other grains with lower bushel weights, the cooling time with a given airflow rate will be reduced in proportion to the reduction in bushel weight.

eration as listed above for fall aeration will extend over 12 days. The disadvantage of delaying aeration until winter is that it not only takes more hours of fan operation but also there are fewer hours of suitable weather each day. In the winter a month or more is often required to cool a bin of grain.

In the above discussion it is assumed that the outdoor temperatures during aeration are cool enough to establish the desired grain temperature. If aeration is started during warm weather and the grain temperatures reduced by stages[3] as the outdoor temperature falls, the total aeration time is increased accordingly. For example, summer-harvested grain may be cooled in two complete stages—possibly to 70° immediately and then to 40° in the fall. Fans then operate about twice as long as they do if aeration is postponed until cooler weather arrives when fans are operated continuously until the grain has reached the desired temperature. The estimates of the typical times required to cool the grain do not include the time when the temperature of the air being circulated is higher than the desired final temperature of the grain.

## AERATION FOR PURPOSES OTHER THAN TEMPERATURE CONTROL

Aeration systems are often used for purposes other than to establish and maintain desired grain temperatures. Such uses include:

1. Distributing gaseous fumigants through the grain.
2. Removing undesirable odors.
3. Equalizing moisture of blended grain.
4. Holding moist grain for brief periods of time.

A few observations were made on the use of aeration systems for the fumigation of grain. Good distribution of fumigant was accomplished in deep bins without recirculation. Operators reported varied success from fumigation trials in flat storages. Generally, the air distribution through the grain was not sufficiently uniform in aeration systems in flat storage for satisfactory fumigation without recirculation. Usually, flat storages are not sufficiently airtight to prevent loss of a considerable amount of the fumigant applied through the aeration system.

Many grain storage operators will attest to the effectiveness of aeration in maintaining the "fresh" odor in stored grain. Objective measurement of odors is difficult, and no attempt was made to assess the value of aeration for odor removal.

Successful use of aeration systems for equalizing the moisture content of blended grain and for holding high-moisture grain for short periods of time have been reported. However, these practices were not observed in either the Iowa or the Indiana tests.

## COSTS OF OPERATING AERATION SYSTEMS

Costs of operating systems depend largely on the following:

1. Airflow rate used.
2. Uniformity of airflow through the grain.
3. Depth of the grain.
4. Kind of grain.
5. Number of cooling stages.
6. Amount of spring and summer aeration.
7. Attendant labor required.

If the grain is cooled in a single stage in the fall, the operation cost should be about as shown below:

| | |
|---|---|
| Flat storage of shelled corn | 0.05 cent per bushel |
| Flat storage of wheat | 0.1 cent per bushel |
| Deep storage of shelled corn | 0.1 cent per bushel |
| Deep storage of wheat | 0.2 cent per bushel |

If the grain is cooled in two stages, the total operating cost should be about twice that shown. If the grain is warmed again by aeration in the spring, the additional cost will be about the same as that for cooling in the fall. Operation seldom becomes a major cost item, even with year-round aeration. For example, if shelled corn in a flat storage is aerated at 1/10 c.f.m. per bushel for 6 hours each day of the year, the annual operating cost will be less than 1 cent per bushel.

[3]The time required to cool all of the grain to near the existing air temperature.

## APPENDIX

Table 1.—*Moisture content of stored shelled corn in aeration tests in Iowa: Samples from selected locations in upper 12 feet of corn at specified times during the test period, October 1955–June 1958*

Bin No. 1.—Airflow downward in fall and spring at 1/10 c.f.m. per bushel

| Date | Distance below corn surface | | | | | |
|---|---|---|---|---|---|---|
| | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1955 | | | | | | |
| October | 10.1 | 10.3 | 10.3 | 10.3 | ... | ... |
| December | 11.7 | 11.6 | 11.2 | 10.7 | ... | ... |
| 1956 | | | | | | |
| February | 13.8 | 12.9 | 12.2 | 11.4 | 10.9 | 11.1 |
| April | 12.3 | 12.6 | 12.3 | 11.0 | 11.5 | 10.9 |
| June | 10.6 | 10.9 | 11.4 | 12.0 | 12.3 | 11.2 |
| August | 11.5 | 11.3 | 11.3 | 11.8 | 12.2 | 11.6 |
| October | 11.5 | 11.0 | 11.3 | 11.8 | 11.9 | 11.4 |
| December | 13.7 | 12.8 | 12.8 | 12.2 | 11.5 | 11.0 |
| 1957 | | | | | | |
| February | 15.8 | 14.9 | 13.4 | 12.1 | 11.8 | 11.2 |
| April | 15.1 | 15.3 | 13.9 | 12.1 | 12.0 | 11.1 |
| June | 11.7 | 11.7 | 12.3 | 12.9 | 13.1 | 11.9 |
| August | 12.2 | 12.2 | 12.4 | 13.3 | 12.9 | 12.1 |
| October | 13.5 | 13.0 | 12.8 | 12.7 | 12.5 | 12.1 |
| December | 13.1 | 13.0 | 12.8 | 13.3 | 13.5 | 12.1 |
| 1958 | | | | | | |
| February | 14.8 | 14.5 | 13.8 | 13.6 | 13.5 | 12.9 |
| April | ... | ... | ... | ... | ... | ... |
| July (final) | 12.2 | 11.9 | 11.2 | 12.0 | ... | ... |

Bin No. 8.—Airflow downward in fall and spring at 1/100 c.f.m. per bushel

| Date | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
|---|---|---|---|---|---|---|
| 1955 | | | | | | |
| October | 10.9 | 10.8 | 10.7 | 10.8 | ... | ... |
| December | 14.3 | 12.8 | 12.0 | 11.0 | ... | ... |
| 1956 | | | | | | |
| February | 14.6 | 14.2 | 12.7 | 10.8 | 10.5 | 10.4 |
| April | 12.9 | 14.3 | 12.7 | 10.6 | 10.5 | 10.3 |
| June | 10.8 | 10.9 | 11.8 | 12.5 | 11.8 | 11.2 |
| August | 12.0 | 11.8 | 11.8 | 12.8 | 12.2 | 11.6 |
| October | 11.4 | 11.5 | 12.0 | 12.3 | 11.4 | 10.8 |
| December | 13.5 | 13.1 | 12.6 | 11.3 | 11.0 | 10.6 |
| 1957 | | | | | | |
| February | 15.2 | 14.5 | 13.6 | 11.5 | 11.3 | 10.8 |
| April | 14.4 | 14.2 | 13.1 | 11.4 | 11.4 | 10.8 |
| June | 14.7 | 13.5 | 13.8 | 13.4 | 12.4 | 12.2 |
| August | 12.9 | 13.1 | 13.6 | 13.9 | 13.0 | 12.2 |
| October | 13.5 | 13.3 | 12.9 | 12.8 | 12.4 | 11.8 |
| December | 14.6 | 14.5 | 14.5 | 12.6 | 12.4 | 11.4 |
| 1958 | | | | | | |
| February | 15.1 | 15.0 | 14.4 | 12.8 | 12.3 | 11.3 |
| July (final) | 13.0 | ... | 12.5 | 14.2 | ... | ... |

Table 1.—*Moisture content of stored shelled corn in aeration tests in Iowa: Samples from selected locations in upper 12 feet of corn at specified times during the test period, October 1955–June 1958*—Continued

Bin No. 3.—Airflow downward in fall and spring at 1/30 c.f.m. per bushel

| Date | Distance below corn surface | | | | | |
|---|---|---|---|---|---|---|
| | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1955 | | | | | | |
| October | 11.1 | 11.1 | 11.2 | 10.8 | ........... | ........... |
| December | 13.1 | 12.8 | 12.3 | 10.9 | ........... | ........... |
| 1956 | | | | | | |
| February | 14.2 | 13.5 | 13.1 | 11.4 | 10.7 | 10.4 |
| April | 11.2 | 11.7 | 12.3 | 11.2 | 11.2 | 10.6 |
| June | 10.8 | 11.1 | 12.0 | 12.3 | 12.0 | 10.6 |
| August | 12.0 | 12.2 | 12.2 | 12.6 | 12.2 | 11.2 |
| October | 11.2 | 11.8 | 12.1 | 12.3 | 11.7 | 10.7 |
| December | 12.6 | 12.6 | 12.5 | 11.4 | 11.0 | 10.5 |
| 1957 | | | | | | |
| February | 15.1 | 14.0 | 13.5 | 12.1 | 11.2 | 10.8 |
| April | 14.7 | 14.7 | 13.6 | 12.0 | 11.4 | 10.9 |
| June | 12.1 | 12.7 | 13.7 | 12.9 | 12.5 | 11.7 |
| August | 12.3 | 12.3 | 12.9 | 13.7 | 13.0 | 11.9 |
| October | 13.0 | 12.5 | 12.3 | 12.3 | 12.2 | 11.3 |
| December | 13.3 | 13.0 | 13.3 | 13.1 | 12.5 | 11.6 |
| 1958 | | | | | | |
| February | 14.8 | 15.2 | 14.1 | 13.3 | 12.8 | 11.4 |
| July (final) | 12.4 | 12.0 | 11.5 | 13.3 | ........... | ........... |

Bin No. 7.—Airflow downward in fall and spring at 1/30 c.f.m. per bushel

| Date | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
|---|---|---|---|---|---|---|
| 1955 | | | | | | |
| October | 11.1 | 11.2 | 11.1 | 11.3 | ........... | ........... |
| December | 13.4 | 13.0 | 12.6 | 11.0 | ........... | ........... |
| 1956 | | | | | | |
| February | 14.6 | 13.8 | 12.5 | 11.5 | 10.8 | 10.4 |
| April | 11.2 | 12.5 | 12.3 | 12.0 | 11.3 | 10.8 |
| June | 11.1 | 11.4 | 12.0 | 13.0 | 12.2 | 11.1 |
| August | 11.8 | 11.7 | 11.9 | 12.6 | 12.4 | 11.5 |
| October | 11.4 | 11.6 | 11.8 | 12.5 | 12.1 | 10.8 |
| December | 12.6 | 12.6 | 12.5 | 11.4 | 11.1 | 11.0 |
| 1957 | | | | | | |
| February | 14.6 | 14.5 | 13.7 | 11.9 | 11.6 | 11.0 |
| April | 14.2 | 14.2 | 13.3 | 12.2 | 11.7 | 10.8 |
| June | 12.4 | 12.7 | 13.7 | 13.3 | 12.5 | 11.7 |
| August | 12.4 | 12.4 | 12.8 | 13.9 | 13.3 | 12.0 |
| October | 13.0 | 12.8 | 12.8 | 12.6 | 12.6 | 11.6 |
| December | 13.4 | 13.4 | 13.3 | 13.4 | 12.8 | 11.9 |
| 1958 | | | | | | |
| February | 15.4 | 14.8 | 14.0 | 13.8 | 13.1 | 11.5 |
| July (final) | 12.8 | 12.2 | 11.4 | 13.7 | ........... | ........... |

Bin No. 5—Airflow upward in fall only at 1/10 c.f.m. per bushel

| Date | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
|---|---|---|---|---|---|---|
| 1955 | | | | | | |
| October | 10.7 | 10.5 | 10.4 | 10.6 | ........... | ........... |
| December | 15.4 | 12.8 | 11.0 | 10.6 | ........... | ........... |
| 1956 | | | | | | |
| February | 11.8 | 10.7 | 10.1 | 10.1 | 10.4 | 10.1 |
| April | 11.1 | 11.5 | 10.3 | 10.1 | 10.3 | 9.9 |
| June | 12.3 | 12.0 | 11.8 | 11.2 | 10.9 | 10.4 |
| August | 11.9 | 11.9 | 11.9 | 11.2 | 11.0 | 11.0 |
| October | 11.4 | 11.7 | 11.5 | 10.7 | 10.6 | 10.4 |
| December | 22.0 | 16.6 | 12.5 | 10.7 | 10.5 | 10.1 |

TABLE 1.—*Moisture content of stored shelled corn in aeration tests in Iowa: Samples from selected locations in upper 12 feet of corn at specified times during the test period, October 1955–June 1958*—Continued

Bin No. 5—Airflow upward in fall only at 1/10 c.f.m. per bushel—Continued

| Date | Distance below corn surface | | | | | |
|---|---|---|---|---|---|---|
| | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1957 | | | | | | |
| February | 13.9 | 12.7 | 11.0 | 10.5 | 10.4 | 10.1 |
| April | 14.3 | 12.7 | 11.2 | 10.5 | 10.4 | 10.1 |
| June | 14.4 | 13.4 | 12.4 | 11.0 | 10.8 | 10.5 |
| August | 12.3 | 12.5 | 12.9 | 11.5 | 11.4 | 10.9 |
| October | 12.3 | 11.6 | 11.1 | 10.7 | 10.6 | 10.1 |
| December | 13.5 | 12.1 | 11.1 | 10.4 | 10.4 | 10.2 |
| 1958 | | | | | | |
| February | 14.8 | 13.8 | 11.5 | 10.3 | 10.3 | 10.1 |
| July (final) | 13.1 | 12.8 | 12.5 | 10.9 | ... | ... |

Bin No. 6.—Airflow upward in fall only at 1/10 c.f.m. per bushel

| Date | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
|---|---|---|---|---|---|---|
| 1955 | | | | | | |
| October | 10.7 | 10.9 | 10.5 | 10.8 | ... | ... |
| December | 10.7 | 11.0 | 10.7 | 11.0 | ... | ... |
| 1956 | | | | | | |
| February | 12.9 | 11.1 | 11.1 | 10.9 | 11.4 | 11.4 |
| April | 11.7 | 11.1 | 11.1 | 10.8 | 11.2 | 11.4 |
| June | 12.2 | 12.0 | 11.5 | 11.2 | 12.0 | 11.8 |
| August | 11.7 | 11.6 | 11.7 | 12.0 | 12.4 | 12.3 |
| October | 12.3 | 12.2 | 11.9 | 11.7 | 12.0 | 11.6 |
| December | 28.9 | 16.5 | 12.4 | 11.4 | 11.8 | 11.4 |
| 1957 | | | | | | |
| February | 15.6 | 13.7 | 11.8 | 11.2 | 11.4 | 11.1 |
| April | 14.3 | 13.6 | 11.8 | 11.2 | 11.4 | 11.3 |
| June | 14.4 | 13.6 | 12.7 | 11.8 | 11.8 | 11.6 |
| August | 12.4 | 12.5 | 12.8 | 12.3 | 12.6 | 12.2 |
| October | 12.6 | 11.8 | 11.1 | 11.2 | 11.4 | 11.2 |
| December | 14.7 | 13.4 | 11.6 | 11.2 | 11.4 | 11.2 |
| 1958 | | | | | | |
| February | 18.4 | 13.7 | 11.7 | 11.3 | 11.3 | 11.3 |
| July (final) | 13.8 | 13.2 | 12.0 | ... | 12.0 | ... |

Bin No. 2—Airflow downward in fall and upward in spring at 1/50 c.f.m. per bushel

| Date | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
|---|---|---|---|---|---|---|
| 1955 | | | | | | |
| October | 13.4 | 13.6 | 13.4 | 12.3 | ... | ... |
| December | 16.1 | 14.4 | 13.1 | 11.8 | ... | ... |
| 1956 | | | | | | |
| February | 16.5 | 16.0 | 14.0 | 11.1 | 11.4 | 10.7 |
| April | 15.2 | 15.0 | 13.5 | 11.0 | 11.7 | 10.6 |
| June | 12.0 | 12.5 | 12.8 | 11.8 | 11.5 | 10.6 |
| August | 12.6 | 12.8 | 13.6 | 12.0 | 11.9 | 11.2 |
| October | 11.4 | 12.0 | 13.1 | 11.7 | 11.4 | 10.6 |
| December | 13.5 | 12.9 | 12.9 | 11.2 | 11.3 | 10.3 |
| 1957 | | | | | | |
| February | 15.1 | 14.4 | 13.3 | 11.6 | 11.8 | 10.6 |
| April | 15.0 | 14.2 | 13.3 | 11.6 | 11.5 | 10.6 |
| June | 12.8 | 13.1 | 13.3 | 11.7 | 11.8 | 10.9 |
| August | 12.5 | 13.1 | 13.6 | 12.7 | 12.4 | 11.1 |
| October | 13.9 | 13.4 | 13.0 | 12.2 | 12.0 | 11.0 |
| December | 14.6 | 14.5 | 13.9 | 12.2 | 11.9 | 10.8 |
| 1958 | | | | | | |
| February | 15.8 | 14.9 | 14.2 | 12.0 | 11.8 | 10.8 |
| April | 15.1 | 15.1 | 14.3 | 12.2 | 11.7 | 10.8 |
| July (final) | 14.0 | ... | 14.4 | 12.5 | ... | ... |

TABLE 1.—*Moisture content of stored shelled corn in aeration tests in Iowa: Samples from selected locations in upper 12 feet of corn at specified times during the test period, October 1955–June 1958*—Continued

Bin No. 12.—Overhead bin with top 15 feet of corn aerated

| Date | Distance below corn surface | | | | | |
|---|---|---|---|---|---|---|
| | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1956 | | | | | | |
| February | 11.7 | 11.5 | 11.4 | 11.4 | 11.2 | 11.2 |
| April | 10.7 | 11.0 | 11.2 | 10.9 | 11.0 | 10.9 |
| June | 11.3 | 11.6 | 11.8 | 11.8 | 12.0 | 11.5 |
| August | 12.1 | 12.1 | 12.0 | 12.3 | 12.6 | 12.0 |
| October | 11.1 | 11.7 | 11.5 | 11.6 | 11.9 | 11.5 |
| December | 14.8 | 13.8 | 12.1 | 11.3 | 11.6 | 11.2 |
| 1957 | | | | | | |
| February | 14.1 | 13.2 | 12.4 | 11.7 | 11.3 | 11.4 |
| April | 13.7 | 13.0 | 12.5 | 11.9 | 11.7 | 11.2 |
| June | 13.8 | 14.0 | 13.8 | 12.5 | 12.2 | 11.7 |
| August | 12.2 | 11.7 | 11.2 | 12.7 | 12.6 | 11.7 |
| October | 12.1 | 12.0 | 11.8 | 11.9 | 11.8 | 11.2 |
| December | 11.9 | 11.9 | 11.9 | 11.9 | 10.9 | 11.4 |
| 1958 | | | | | | |
| February | 12.2 | 12.0 | 12.0 | 11.9 | 11.0 | 11.3 |
| April | 13.0 | 12.2 | 11.7 | 12.1 | 11.0 | 11.4 |
| July (final) | 12.3 | 12.2 | 12.0 | 12.0 | 12.5 | 11.5 |

Bin No. 14.—Overhead bin with no aeration

| Date | Under 0.5 foot | 0.5 – 1 foot | 1 – 2 feet | 4 – 5 feet | 6 feet | 12 feet |
|---|---|---|---|---|---|---|
| 1958 | | | | | | |
| July (final) | 23.8 | 19.5 | 14.7 | 11.6 | 11.8 | 11.2 |

TABLE 2.—*Comparison of corn temperatures in two bins aerated at 1/10 c.f.m. per bushel: Bin No. 1, airflow downward in fall and spring and No. 5, airflow upward in fall only*

| Distance below surface (Feet) | Corn temperatures | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct. 1955 | | Mar. 1956 | | Sept. 1956 | | Apr. 1957 | | Sept. 1957 | | Mar. 1958 | |
| | Bin 1 | Bin 5 | Bin 1 | Bin 5 | Bin 1 | Bin 5 | Bin 1 | Bin 5 | Bin 1 | Bin 5 | Bin 1 | Bin 5 |
| | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* |
| 6 | 55 | ...... | 35 | ...... | 74 | ...... | 36 | ...... | 61 | ...... | 30 | ...... |
| 12 | 67 | 69 | 24 | 36 | 70 | 78 | 31 | 38 | 76 | 64 | 28 | 32 |
| 18 | 66 | 72 | 25 | 27 | 68 | 78 | 32 | 36 | 71 | 83 | 29 | 36 |
| 24 | 70 | 77 | 24 | 26 | 69 | 78 | 32 | 35 | 69 | 78 | 28 | 36 |
| 30 | 67 | 79 | 22 | 25 | 70 | 75 | 31 | 35 | 68 | 72 | 28 | 37 |
| 36 | 69 | 82 | 19 | 26 | 69 | 68 | 31 | 35 | 67 | 65 | 28 | 38 |
| 42 | 75 | 79 | 19 | 25 | 69 | 62 | 30 | 35 | 65 | 60 | 25 | 39 |
| 48 | 83 | 80 | 22 | 25 | 69 | 57 | 28 | 35 | 63 | 57 | 21 | 40 |
| 54 | 83 | 76 | 26 | 24 | 68 | 54 | 27 | 36 | 62 | 56 | 18 | 40 |
| 60 | 84 | 75 | 26 | 22 | 67 | 54 | 27 | 36 | 62 | 55 | 19 | 39 |
| 66 | 86 | 71 | 23 | 21 | 65 | 53 | 26 | 36 | 63 | 55 | 22 | 39 |
| 72 | 89 | 65 | 21 | 19 | 63 | 51 | 26 | 35 | 63 | 54 | 25 | 38 |
| 78 | 89 | 58 | 21 | 18 | 61 | 51 | 26 | 35 | 63 | 54 | 25 | 37 |
| 84 | 88 | 56 | 23 | 16 | 60 | 51 | 27 | 34 | 62 | 55 | 25 | 35 |
| 90 | 85 | 57 | 25 | 16 | 59 | 50 | 27 | 32 | 61 | 55 | 24 | 32 |
| 96 | 75 | 55 | 27 | 17 | 58 | 50 | 27 | 29 | 61 | 55 | 23 | 28 |
| 102 | 65 | 55 | 27 | 17 | 57 | 51 | 25 | 26 | 60 | 55 | 23 | 23 |
| 108 | 54 | 58 | 22 | 19 | 60 | 53 | 25 | 28 | 65 | 58 | 23 | 24 |



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